Daily Energy Expenditure Across the Course of Lactation Among Urban Bangladeshi Women

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ABSTRACT Measures of energy intake of lactating women in developing countries show that intakes are often lower than those recommended by international bodies, while fat-mass losses are often substantially less than the 3–4 kg used in the calculations of recommendations, suggesting that physiological adaptation must be commonplace among such women. The cost of lactation may be met by reduction in energy expenditure, including reduced physical activity, as well as by mobilization of bodily soft tissue. However, daily energy expenditure of lactating women has been shown to increase across the course of lactation among women in a rural population in the Philippines and an urban population in India, with a decline in body weight across the course of lactation in both studies. In the present study, total daily energy expenditure and anthropometric body composition were measured longitudinally in 68 mothers from a poor urban area of Dhaka, Bangladesh, at 0, 1, 2, 4, and 8 months of lactation, to determine whether the increasing energy expenditure across lactation observed elsewhere also occurs in Bangladeshi women. In addition, the extent to which an extended period of lactation was accompanied by weight and body fat change in these women was determined. Energy expenditure by heart-rate monitoring and activity report, and body composition from anthropometry was carried out four times across the 8-month period of lactation. A small decline in body fat mass and a significant increase in total energy expenditure across this period were observed, confirming similar observations elsewhere in the developing world. Am J Phys Anthropol 110:457–465, 1999.

Breastfeeding performance of women in developing countries is considered adequate in comparison with women in industrialized nations (Orr-Ewing et al., 1986; Prentice & Prentice, 1995). Given the generally low bodily energy reserves of women in developing countries, the issue of energy-saving adaptations to accommodate the cost of lactation, where fat gains across pregnancy are low, has been addressed by various authors (Prentice and Prentice, 1990; Coward et al., 1992; Lunn, 1994;Ulijaszek, 1995). While the cost of lactation can be met by increased food consumption, adaptations to low food availability during lactation may include reduced physical activity, reduced basal metabolic rate, reduced thermic effect of food, or the use of body fat stores (Lunn, 1994). The FAO/WHO/UNU (1985) recommend that an additional energy allowance of 2.1 MJ/day across the first 6 months of

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lactation, provided that 3–4 kg of maternal body fat reserves are utilized in breast-milk production across this time. However, measures of energy intake of lactating women in developing countries show that intakes are often lower than those recommended (Arroyave, 1975; Norgan et al., 1974; Schutz et al., 1980; Hassan and Ahmad, 1984; Delgado et al., 1985; Ulijaszek, 1987; Piers, 1994), while fat-mass losses are often substantially less than the 3–4 kg used in the calculations of recommendations (Orr-Ewing, 1985; Piers, 1994), suggesting that physiological adaptation must be commonplace among lactating women in less-industrialized countries.

In addition to the increase in energy intake and mobilization of maternal fat stores, part of the cost of lactation may be met by reduction in energy expenditure, including reduced physical activity (Sadurskis et al., 1988; Roberts et al., 1982; van Raaij et al., 1990; Ulijaszek, 1995) or by enhanced efficiency of energy metabolism (Illingworth et al., 1986; Sadurskis et al., 1988; van Raaij et al., 1991; Spurr et al., 1998). However, daily energy expenditure of lactating women has been shown to increase across the course of lactation among women in a rural population in the Philippines (Guillermo-Tuazon et al., 1992) and an urban population in India (Piers et al., 1995). In the former case, this is accompanied by an energy intake 0.95 MJ/day above that in early pregnancy, but which does not vary across the course of lactation. In the latter case, it is accompanied by an energy intake which is 2.02 MJ/day above that in early pregnancy, at 12 weeks post-partum, but which declines to a value 1.51 MJ/day above the early pregnancy level, at 24 weeks post-partum. In both studies, women showed a decline in body weight across the course of lactation. In the Philippines study, fat mass constituted 0.6 kg of the total 1.4 kg loss, while in the India study, overall weight loss was 0.3 kg, while loss of fat mass was 0.5 kg, suggesting an overall gain in muscle mass. In the present study, total daily energy expenditure (TDEE) and anthropometric body composition were measured in 68 mothers from a poor urban area of Dhaka, Bangladesh, at 0, 1, 4, and 8 months of lactation, to determine whether the increasing energy expenditure across lactation observed in poor Filipino women (Guillermo-Tuazon et al., 1992) and in well-nourished Indian women (Piers, 1994) also occurs in Bangladeshi women. In addition, the extent to which an extended period of lactation is accompanied by weight and body fat change in these women was determined.

MATERIALS AND METHODS

The women of this study lived in Mirpur, on the outskirts of Dhaka, developed in the early 1960s to house people who migrated in 1947 from India to what was then East Pakistan. Soon after the creation of Bangladesh, this area became a relatively cheap place to move into, prompting an influx of poor people into the area. Currently, the majority of people living in Mirpur can be grouped into three broad socio-economic classes. The first includes those who are in government service, and are housed in government quarters which have been built in this area. They comprise the low to middle fixed income group. The second is a middle income group, whose members were able to afford some land in the 1970s on which to build a house, as well as those who rent from someone else. The third and predominant group includes poor and low income individuals who have been forced to take up residence either in cheap rented accommodation or in the slums.

Data was collected at the Radda Barnen (Swedish Save the Children) clinic, whose main function is the provision of antenatal care to a large population of women and children. Recruitment began by the screening of pregnant women attending this clinic for antenatal check-up during the third trimester of pregnancy. All women had no complications of pregnancy, were of reasonable health, and without histories of diabetes, hypertension, or malaria. A total of 97 women were selected, of which 68 completed heart-rate monitoring and calibration against oxygen consumption, at every stage of the study. Only those women with complete sets of measurements were included in this analysis. Mothers were recruited about 1 month prior to expected date of delivery, between September and December 1993, and first measurements were made between

October 1993 and January 1994. Seasonal variation in adult nutritional status has been identified in rural Bangladesh, with mean female weights being on average 1 kg less in the monsoon than in the dry season (Abdullah and Wheeler, 1985). While seasonality of adult weight change has not been documented in urban Bangladesh, livelihood security assessments carried out in three urban centers indicate that income from important sources of employment for the poor, such as laboring on construction sites and rickshaw driving, are severely disrupted during the monsoon season (International Food Policy Research Institute, 1998). Monsoon rains can last up to 3 months during the months June to September, the period of the final round of data collection at month 8 of lactation. Strategies used by the urban poor for coping with times of nutritional stress include reduction in the number of meals eaten, going hungry, and eating poorer quality foods (International Food Policy Research Institute, 1998). In the present survey, seasonality was not controlled for in the analysis. Nutritional seasonality was homogeneous during the first four times of measurement (October 1993 to May 1994), while the fifth time of measurement took place during the monsoon season when conditions might be expected to deteriorate.

Anthropometry was carried out using standard techniques (Weiner and Lourie, 1981), and measures of height, weight, and biceps, triceps, subscapular and suprailiac skin folds were made at the beginning of the study, then again at 1, 2, 4, and 8 months of the study for all measures except height. Weight was measured using battery-operated Soehnle digital scales to the nearest 100 g. Subjects were measured wearing the minimum clothing that was considered culturally decent, and was similar across time and among women. Height was measured using a Harpenden anthropometer to the nearest millimeter. Skin fold thicknesses were measured on the left side of the body to the nearest 0.1 mm using Holtain skin fold calipers. All measurements were made by one trained female field assistant, whose intra-observer measurement error was determined by the remeasurement of ten subjects, at the beginning of the study. Values for technical error of measurement (TEM) and coefficient of reliability (R) are given in Table 1. In all cases, values of R are at or above 0.95, suggesting that anthropometric measurement error was acceptably low (Ulijaszek and Lourie, 1994). Estimations of percent body fat from skin fold measures were made using the formulae of Durnin and Womersley (1974) for four skin fold thicknesses, in association with the Siri (1956) formula. The Durnin and Womersley (1974) equations have been more widely validated against reference body composition methods among different populations than any other (Ulijaszek, 1992). Body mass index (BMI) was calculated from weight and height.

TABLE 1. Intra-observer anthropometric measurement error

Variable	Technical error of measurement (TEM)	Coefficient of reliability (R)
Height (cm)	0.52	0.99
Weight (kg)	0.67	0.99
Skinfolds (mm)		
Biceps	0.32	0.98
Triceps	0.73	0.98
Subscapular	1.02	0.97
Suprailiac	1.32	0.95

All 68 mothers were seen five times across the first 8 post-natal months (0, 1, 2, 4, and 8 months into lactation), and TDEE estimated from measures of heart rate monitoring and retrospective activity questionnaire for periods during the day when heart rate monitoring was not carried out. Heart rate monitoring has been shown to be an appropriate method for the estimation of group levels of energy expenditure (Spurr et al., 1988; Ceesay et al., 1989; Livingstone et al., 1990; Wareham et al., 1997). Subjects wore heart rate monitors (Polar Electro 3000, Finland) for most of the waking day, but removed them in the early evening. It was initially planned that the monitors would be worn until retiring to bed, but subjects complained of great discomfort, and the protocol was modified to ensure compliance. For the time the mother was not observed, activities were recorded retrospectively by questionnaire segmenting the day into significant time frames, for better recall. The time segments used were: (1) from time of re-

moval of heart rate monitor until prayer time at dusk; (2) dusk until bed time; and (3) from getting up in the morning until the arrival of the research assistant. Specific questions were asked about any strenuous activities the women might have engaged in. While it had been planned that heart-rate monitoring be carried out across a period of four consecutive days, poor compliance during the pilot stage of the study necessitated the monitoring period to be reduced to one day at each stage of lactation. The daily variation in activity patterns was low in this group of women (Rahman, 1996), and while the necessarily short period of observation may have reduced the representativeness of the measures as habitual daily energy expenditures, this is unlikely to have been by very much.

Heart rate monitoring was calibrated against oxygen consumption at two rates of exercise performed on a standard step test, as well as while lying down, sitting, and standing. These calibrations were carried out on each woman across the study period, at the time of measurement. The volume and oxygen concentration of expired air were estimated by gas meter and oxygen analyzer (Servomex A340) respectively, and the oxygen consumption per minute of standardized exercise calculated, at standard temperature and pressure. The heat equivalent was based on an assumption that respiratory quotient (RQ) was 1.00, since the women were losing weight across the period of lactation, and that the error involved in not correcting for gas volume is equal and opposite to error of RQ assumption (McLean and Tobin, 1987). Energy expenditure from heart rate was estimated using standard methods (Ceesay et al., 1989; Ulijaszek, 1992). An approximation of the energy expended in physical activity was obtained by subtraction of basal metabolic rate (BMR) predicted from body weight, using the equations of Hayter and Henry (1994). Although the equations of Schofield (1985) have been recommended for the global prediction of BMR (FAO/WHO/UNU, 1985), these have been shown to over-predict BMR among populations living in the tropics (Henry and Rees, 1991). Hayter and Henry (1994) give equations for the prediction of BMR from body weight specific to four populations, including South Asians. The latter equations are based on the largest sample of measurements of BMR and body weight of South Asians thus far available, and are used in preference to the less-specific Henry and Rees (1991) equations derived from measurements of tropical populations, on the unpublished recommendation of C.J.K. Henry (personal communication). In well-nourished women in industrialized countries, BMR shows either little change, or slight elevation in lactation relative to the nonpregnant, nonlactating state (Goldberg et al., 1991, Prentice et al., 1996). In developing countries, studies of BMR of lactating women give more varied results. While longitudinal study of Gambian women showed a significant decline in BMR relative to the nonpregnant, nonlactating state (Lawrence et al., 1986), studies in the Philippines (Guillermo-Tuazon et al., 1992), India (Madhavapeddi and Rao, 1992; Piers et al., 1995) and among Mesoamerindians (Butte et al., 1997) show no such differences. Furthermore, cross-sectional comparisons of the BMR of lactating and nonlactating women in the Gambia (Singh et al., 1987) and Guatemala (Schutz et al., 1980) show no significant differences between them. Thus, with one exception, data from the developing countries support the conclusions drawn from studies in industrialized countries (Prentice et al., 1996). In the absence of BMR prediction equations derived from the measurement of lactating women, in the present study, it was deemed acceptable to use equations based upon measurements of BMR of nonlactating women.

Estimates of daily energy made available from the breakdown of bodily adipose and muscle tissues came from values for the catabolism of these tissues. These were 39.1 kJ/g of body fat metabolized, and 18.5 kJ/g of protein metabolized (Brockway, 1987). Energy available for physical activity and lactation combined was estimated assuming that the BMR remains stable and related only to changes in body size across the course of lactation, and that the thermic effect of food (TEF) does not change. This was shown to be the case in an Indian sample (Piers et al., 1995). Furthermore, in a review of the limited literature of TEF during lactation, Pren-

TABLE 2. Sociodemographic variables

	N	%
Age of mother		
<24 years	44	65
≥24 years	24	35
Sex of present child		
Male	34	50
Female	34	50
No. of previous living children		
<2	46	68
≥2	22	32
Mother's education		
Secondary	15	22
Grade 5–9	23	34
Grade 1–4	16	24
None	14	21
Religion		
Islam	63	93
Hindu	3	4
Christian	2	3
Total income of family		
<Tk2000	15	22
Tk2000–5000	30	44
>Tk5000	23	34
Type of house lived in		
Brick	21	31
Tin shed	41	60
Thatched	6	9

tice et al. (1996) concluded that there is no clear evidence that diet-induced thermogenesis (an alternative term for the TEF) changes during lactation. Statistical analysis was carried out using the statistical package for the social sciences for portable computer (SPSS-PC+), using repeated measures analysis of variance.

RESULTS

Socio-demographic variables are summarized in Table 2. The majority of mothers were young, being either primiparous or having two or fewer previous children. The majority of mothers had primary school education only, with equal numbers of mothers with either some secondary education, or no education at all, respectively. The majority of mothers were below the poverty line, living in tin or thatched roof accommodation. Mean height of mothers was 153.5 cm. Table 3 gives mean weight, BMI, skin fold thicknesses, and percent body fat across the 8-month period of lactation. Weight shows a decline across the course of lactation, with the biggest difference occurring between months 1 and 2 of lactation. Post hoc Sheffe tests reveal that this difference is statistically significant ($P < 0.05$), and that the weight at birth does not differ significantly from weight at 1 month of lactation, but is significantly greater than weight at 2, 4, and 8 months of lactation ($P < 0.05$). The BMI shows a very similar pattern of decline across the course of lactation to that of weight, with BMI at birth being significantly higher than that at 2, 4, and 8 months of lactation, but not at 1 month of lactation. The BMI at 1 month of lactation is also significantly higher than that at 2, 4, and 8 months of lactation. Skin fold thicknesses show no significant declines across the period of lactation. Percent body fat and weight of fat both show slight, nonsignificant declines across this period. Loss of body fat mass across 4 months of lactation is 0.21 kg, while across 8 months of lactation it is 0.43 kg. This is similar to the pattern of weight and body fat loss reported for poor women in the Philippines by Guillermo-Tuazon et al (1992), and represents a daily negative energy balance of about 60 kJ across the 8-month period. Fat-free weight shows a significant decline across the course of lactation which mirrors that of body weight and BMI, with values at birth showing no difference to that at 1 month, but being significantly higher than at 2, 4, and 8 months of lactation. This suggests an extensive mobilization of muscle tissue, relative to that of fat, as energy.

Table 4 shows mean TDEE and energy expended in physical activity plus thermic effect of food. The TDEE increases across the period of lactation, in absolute terms ($P < 0.05$), and as expressed per kilogram body weight ($P < 0.01$), and per kilogram of fat-free mass ($P < 0.01$). Post hoc Sheffe tests show that all three expressions of daily energy expenditure at birth and at month 1 of lactation do not differ from each other, but differ from energy expenditure at months 2, 4, and 8 of lactation (all $P < 0.05$, except total daily energy expenditure (MJ/day) comparison of months 1 and 8 ($P < 0.01$), and TDEE (kJ/kg/day, and kJ/kg FFM/day) comparisons of months 1 and 2). Thus the most substantial increase in energy expenditure per unit body size comes after the first month of lactation, and is due to decline in body weight, fat-free weight, and increase in TDEE. The difference between TDEE and

TABLE 3. Mean weight, body mass index (BMI) and percent body fat across the period of lactation (standard deviations given in parentheses)

Time (months)	Weight (kg)	BMI	Skin folds (mm) Biceps	Triceps	Subscapular	Suprailiac	Body fat (%)	Fat weight (kg)	Fat-free weight (kg)
0	48.0	20.3	6.0	12.7	13.6	13.3	26.1	12.5	35.5
	(7.9)	(2.9)	(2.5)	(4.4)	(5.2)	(6.2)	(5.1)	(2.4)	(7.4)
1	47.7	20.2	5.6	13.0	13.0	13.2	25.9	12.3	35.4
	(8.0)	(2.8)	(2.5)	(4.9)	(4.9)	(6.5)	(5.3)	(2.5)	(7.5)
2	47.2	19.9	6.1	13.1	13.1	13.1	26.0	12.3	34.9
	(8.5)	(3.1)	(2.9)	(4.6)	(5.1)	(6.4)	(5.3)	(2.5)	(7.9)
4	46.9	19.8	6.0	13.4	13.0	14.0	26.2	12.3	34.6
	(8.6)	(3.2)	(2.9)	(4.9)	(5.1)	(7.1)	(5.5)	(2.6)	(8.0)
8	46.8	19.8	5.8	13.1	12.8	13.8	25.8	12.1	34.7
	(8.9)	(3.4)	(5.8)	(5.5)	(5.7)	(7.2)	(5.9)	(2.8)	(8.3)
Repeated measures analysis of variance:									
F	4.6	4.1	1.8	3.2	3.0	2.3	2.2	2.0	4.2
P	<0.05	<0.05	ns	ns	ns	ns	ns	ns	<0.05

TABLE 4. Mean daily energy expenditure

Time (months)		Total daily energy expenditure (TDEE) (MJ/day)	(kJ/kg/day)	(kJ/kgFFM/day)	Activity + lactation + thermic effect of food (TDEE-predicted BMR) (MJ/day)	(kJ/kg/day)
0	Mean	8.30	176	238	3.20	67
	(SD)	(0.99)	(29)	(31)	(0.55)	(9)
1	Mean	8.28	176	237	3.19	67
	(SD)	(0.92)	(25)	(28)	(0.58)	(10)
2	Mean	8.55	184	248	3.47	74
	(SD)	(0.94)	(28)	(30)	(0.64)	(11)
4	Mean	8.58	188	254	3.51	75
	(SD)	(0.94)	(27)	(26)	(0.68)	(9)
8	Mean	8.64	188	254	3.57	76
	(SD)	(0.95)	(27)	(26)	(0.74)	(12)
Repeated measures analysis of variance:						
	F	5.3	7.1	9.8	12.3	9.4
	P	<0.05	<0.01	<0.01	<0.001	<0.01

predicted BMR is the sum of energy expended in physical activity, lactation, and the TEF. This shows significant increase across the course of lactation when expressed both in absolute terms, and per unit of body mass. Post hoc Sheffe tests show significant differences between expenditure at and prior to 1 month of lactation, and expenditure at and subsequent to 2 months of lactation for both variables ($P < 0.05$).

Table 5 shows calculations of the energy mobilized from fat and lean tissue across the course of lactation, and the daily energy available for physical activity and the thermic effect of food. While fat mobilization as energy does not vary across lactation, protein mobilization does. Muscle is the predominant source of energy fueling negative energy balance among these women between 0 and 4 months of lactation, with energy mobilized from fat stores becoming more important between 4 and 8 months of lactation. Energy mobilization from fat and

TABLE 5. Daily energy mobilized from fat and muscle tissue, calculated from metabolic cost of specific tissue metabolism

Period (months)		Energy mobilized (kJ/day) from Fat	Muscle	Total
0–4	Mean	77	131	208
	(SD)	(82)	(118)	(114)
4–8	Mean	71	−18	53
	(SD)	(51)	(73)	(70)
Paired *t*-test:				
	T	0.51	8.9	9.6
	P	ns	<0.001	<0.001

protein stores combined is four times greater during months 0 to 4 of lactation than during months 4 to 8 ($P < 0.001$). Assuming no change in physical activity, basal metabolic rate and TEF, the greater energy expenditure at 4 months lactation relative to that at the onset of lactation represents a greater daily intake of 280 kJ, which, linked to a negative energy balance due to weight loss of 208 kJ/day represents an additional 488 kJ/day available for breast milk synthesis, a value which is less than one-quarter of that recommended by FAO/WHO/UNU (1985). The greater energy expenditure at 8 months lactation relative to 4 months lactation represents an additional daily intake of 60 kJ, which linked to a negative energy balance of 53 kJ/day, represents a further 113 kJ/day available for breast milk synthesis, giving a cumulative value that is still well below the level recommended by FAO/WHO/UNU (1985).

DISCUSSION

Urban poor Bangladeshi women show a decline in body fat mass that is much lower than the level built into calculations of energy requirements in lactation by FAO/WHO/UNU (1985). This is in agreement with the observations of Orr-Ewing (1985) of lactating women in Papua New Guinea, and Piers (1994) in India. Furthermore, the additional energy expenditure in physical activity, lactation, and the TEF is 280 kJ/day greater than at birth after 4 months lactation, and 340 kJ/day after 8 months lactation. The possibility that this increase in energy expenditure may be due to physical activity, as in the Philippines (Guillermo-Tuazon et al., 1992), can be assessed by partitioning this composite value according to assumptions made in estimating the energy requirements of lactation (Prentice et al., 1996). These are that (1) the TEF does not alter across the course of lactation; (2) the energy cost of breast milk production at 83% efficiency is 3.37 kJ/g; and (3) breast milk volumes increase from 680 g/day at 0–1 months of lactation to 830 g/day at 3–6 months, declining to 625 g/day at 12 months for women who fully breastfeed. The third assumption is based on data collected in Sweden, the United States, and the United Kingdom, but is valid in the present context given the similarity of breast milk output of women in developed and developing countries (Prentice et al., 1986). Removing the estimated energy cost of breast milk production leaves a value for the energy cost of physical activity and TEF that varies little across the first 4 months of lactation, but which is considerably higher at 8 months of lactation. If breast milk output values for partial breastfeeding (Prentice et al., 1996) at months 4 and 8 are used instead of values for full breastfeeding, then the increase in total energy expenditure can be attributed to increased physical activity from 4 months lactation onward.

If seasonality was an important influence on the nutritional status of these women, it would be expected that declines in body weight and energy expenditure would be large between months 4 and 8 of the study, since the last phase of data collection took place during the monsoon, when nutritional conditions generally deteriorate in Bangladesh. The absence of such an effect might suggest that this urban population of poor adult females is relatively buffered against seasonal nutritional stress, although the links between seasonal occupation, income, and nutrition need to be established in urban Bangladesh.

The values for TDEE in the present study are comparable to the higher values reported for women in developing countries (Pasquet and Koppert, 1993), being equivalent to female sweet potato cultivators in the Highlands of Papua New Guinea (Norgan et al., 1974), Nepali cultivators (Panter-Brick, 1993), millet cultivators in Burkina Faso (Bleiberg et al., 1980), and female Igloolik hunters in Canada (Shephard, 1974). They also confirm, in another population, the rise in energy expenditure across the course of lactation observed in the Philippines by Guillermo-Tuazon et al. (1992), and in India by Piers et al. (1995).

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